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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The development of a model to estimate 30 kt and 50 kt wind probabilities from tropical cyclone forecasts in the North Indian Ocean is described.

The model is based on position forecast errors, which are used to determine the probability of a cyclone occupying a particular geographical position, and on wind profile errors. Wind profile errors consist of errors in the forecast maximum and errors in the forecast radius of 30 kt and 50 kt winds. The profile errors are used to estimate the probability of 30 kt and 50 kt winds occurring

((continued on reverse))

Block 20, Abstract, continued.

at a point, given that the tropical cyclone occupies a particular position. These position and wind probability elements are combined by using an assumption of independence which was supported by correlation coefficients in an earlier work.

The present model, which includes features of the earlier strike probability model and an Atlantic Ocean wind probability model, is tested on independent data. Test results illustrate good agreement between forecast probability and the frequency of occurrence of 30 kt and 50 kt winds.

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AB (27) The development of a model to estimate 30 kt and 50 kt wind probabilities from tropical cyclone forecasts in the North Indian Ocean is described. The model is based on position forecast errors, which are used to determine the probability of a cyclone occupying a particular geographical position, and on wind profile errors. Wind profile errors consist of errors in the forecast maximum and errors in the forecast radius of 30 kt and 50 kt winds. The profile errors are used to estimate the probability of 30 kt and 50 kt winds occurring at a point, given that the topical cyclone occupies a particular position. These position and wind probability elements are combined by using an assumption of independence which was supported by correlation coefficients in an earlier work. The present model, which includes features of the earlier strike probability model and an Atlantic Ocean wind probability model, is tested on independent data. Test results illustrate good agreement between forecast probability and the frequency of occurrence of 30 kt

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TROPICAL CYCLONE WIND PROBABILITY FORECASTING FOR THE NORTH INDIAN OCEAN (WINDPIO)

Prepared By:

Jerry D. Jarrell
Science Applications, Inc.
Monterey, California 93940

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TROPICAL CYCLONE WIND PROBABILITY FORECASTING FOR THE NORTH INDIAN OCEAN (WINDPIO)

1.0 Introduction

The concepts and development of tropical cyclone wind probability forecasting for the North Indian Ocean follow closely those originally presented by Jarrell[1] (1981) for the western North Pacific. This is the fourth in a series of wind probability forecasting program reports covering different ocean basin areas. The initial report on the western North Pacific was followed by similar reports on the western North Atlantic (Jarrell[2], 1981) and eastern North Pacific (Jarrell[3], 1982). This report and the two previous are based upon an extension of the concepts developed for tropical cyclone strike probability forecasting (Jarrell[4], 1978). As these concepts have been previously presented and the programs are presently operational, a redevelopment of the concepts will not be presented in this report. A brief summary will be presented as a background

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[1]Jarrell, J.D., 1981: Tropical Cyclone Wind Probability Forecasting (WINDP), NAVENVPREDRSCHFAC Contractor Report CR 81-03.

[2]Jarrell, J.D., 1981: Atlantic Hurricane Wind Probability Forecasting (WINDPA), NAVENVPREDRSCHFAC Contractor Report CR 81-04.

[3]Jarrell, J.D., 1982: Tropical Cyclone Wind Probability Forecasting for the Eastern North Pacific (EPWINDP), NAVENVPREDRSCHFAC Contractor Report CR 82-06.

[4]Jarrell, J.D., 1978: Tropical Cyclone Strike Probability Forecasting, NAVENVPREDRSCHFAC Contractor Report CR 78-01.

for the new reader. Differences between the development of North Indian Ocean tropical cyclone wind probabilities and that of its closest previous counterpart, the model for the Atlantic, is the crux of this report and these will be described in detail.

The tropical cyclone wind probability forecasting model generates estimates of the probability of 30 and 50 knot winds occurring at a point given that the tropical cyclone occupies a particular position. The model includes many features of the strike probability model, which is based on an analysis of position forecast errors to determine the probability of a tropical cyclone occupying a particular geographic position. Wind profile errors in the forecast of maximum wind and in the forecast radius of 30 and 50 knot winds are similarly analyzed to determine the 30 and 50 knot probabilities of occurrence.

Jarrell[4] (1978), in the development of the strike probability model, based the theory of strike probability on three assumptions:

1) All tropical cyclone forecasts are subject to error;
2) Difficulty of forecast and size of forecast error are statistically related; and
3) The occurrence of errors is random and approximates a multimodal bivariate normal probability distribution.

Studies by independent investigators in three ocean basins frequented by tropical cyclones verified these assumptions. Nicklin[5] (1977), Thompson et al[6] (1981), and Crutcher et al[7] (1982) using data from the western Pacific, eastern Pacific and the Atlantic, respectively, also developed individual methods to group forecasts into three classes of forecast difficulty. A general relative classification evolved in each study to yield forecast error groups of below average, average, and above average errors. These groups were also referred to as Class I (easy forecasts), Class II (average forecasts) and Class III (difficult forecasts) in previous reports. Each investigator also utilized sufficient statistical data and prescribed sufficient parameters to describe the bivariate normal distributions for each of the three classes and for forecasts of 24, 48, and 72 hours.

Following the work of Crutcher et al[7] the forecast errors were separated into groups using the NORMIX clustering model. Unlike the other basins, only two significantly different clusters were identified. These two clusters are shown by 50% probability ellipses in Figure 1.

---

[5]Nicklin, D.S., 1977: A Statistical Analysis of Western Pacific Tropical Cyclone Forecast Errors, Naval Postgraduate School, M.S. Thesis, June.

[6]Thompson, W.J., R.L. Elsberry and R.G. Read, 1981: An Analysis of Eastern North Pacific Tropical Cyclone Forecast Errors, Monthly Weather Review, V. 109, pp. 1930-1938.

[7]Crutcher, H.L., C.J. Neumann and J.M. Pelissier, 1982: Tropical Storm Forecast Errors and the Multimodal Bivariate Normal Distribution, J. Appl. Meteor., V. 21, pp. 978-987.

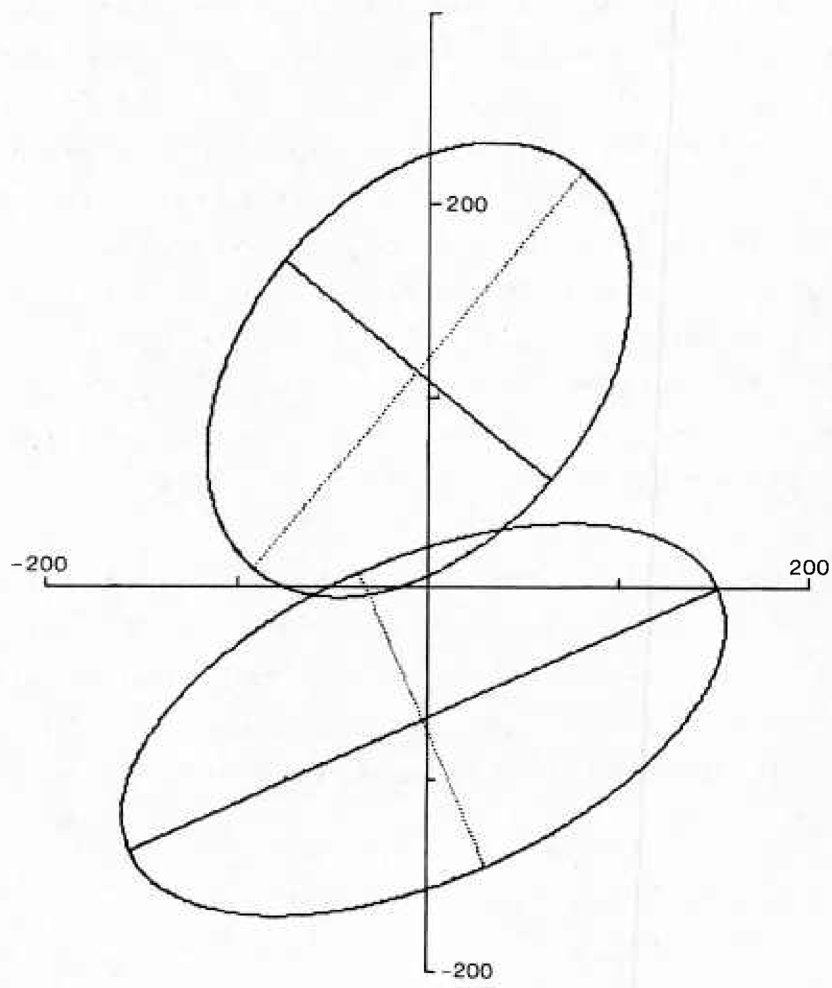

Figure 1. Fifty percent error probability ellipses for two clusters of 24-hr forecast errors identified by the NORMIX clustering model in the North Indian Ocean. Distances are in nautical miles (n mi).

2.0 Model Description

2.1 The North Indian Ocean

One version of the tropical cyclone wind probability model was developed for the Atlantic Ocean as a modification of the western Pacific wind probability program. The concepts of the strike portion of the North Indian Ocean model are similar to those developed for the Atlantic. The North Indian Ocean model uses a regression equation to estimate the probability of a forecast belonging to either of two forecast classes (associated with two forecast error clusters) and the Tsui, et al, model[8] (used in the Atlantic wind probability model) to determine wind profiles and to handle asymmetrical storm distribution. Thus this model uses modified versions of both the wind probability and strike probability concepts used in the Atlantic.

The Atlantic wind profiles and tropical cyclone asymmetry are derived using methods produced by Tsui, et al, as indicated above. Tsui, et al, using wind radius data from tropical cyclone warnings over a 12-year period (1966 to 1977), determined that the profile of the tangential wind speed along the radial axis was exponential. He further determined that maximum wind and persistence could be statistically related to the size of the storm and that the asymmetric shape of the storm's wind pattern could be correlated

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[8]Tsui, T.L., L.R. Brody and S. Brand, 1982: A Technique for Predicting Surface Wind Distributions of Tropical Cyclones in the Western North Pacific, NAVENVPREDRSCHFAC Technical Report TR 82-05.

to the forward speed of movement of the storm. A simple empirical relationship was derived to provide an estimation of any wind radii:

$$V/V_{max} = \exp\ (-0.693R),$$

where V is the wind speed of interest, V_{max} is the maximum wind speed of the storm, and R is a ratio of the radius associated with V to the radius associated with one-half of V_{max} (r_{half}) , respectively.
Radii are measured outward from the radius of maximum winds. Asymmetrical storm configuration is accommodated in the profile by an empirical adjustment of the one-half radius, r_{half}, dependent on bearing relative to direction of motion and translation speed.

3.0 Testing the North Indian Ocean Wind Probability Program (WINDPIO)

The methodology used in comparing WINDPIO predicted values against observed values is identical to that used in the Atlantic. An array of 30 points in the North Indian Ocean was selected (Figure 2). WINDPIO values for the 30 and 50 knots were calculated at 12 hour intervals from the effective synoptic time of the Joint Typhoon Warning Center (JTWC) forecasts for the three 1981 season cyclones. Since most of these 30 points are not observing stations, actual verifying winds were not generally available. Consequently a verifying "warning time" probability greater than 50% constituted a verifying strike.

Tables 1, 2, 3 and 4 compare the expected to the observed occurrences of 30 and 50 knot winds. Predictions are associated with percentage groups of increasing width, <1/2%, 1/2 to 1 1/2%, ..., etc. Time integrated probabilities were verified only if a continuous record was available over the entire time period. Significance of the differences between the expected and the observed, as discussed in previous reports (Jarrell[9], 1981) is difficult to assess, but using a "t" test, agreement is excellent. The difference between the expected and observed occurrences were never at a significant level and, although the sample is extremely small, the overall results are considered statistically sound.

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[9]Jarrell, J.D., 1981: Atlantic Strike Probability Program, NAVENVPREDRSCHFAC Contractor Report CR 81-04.

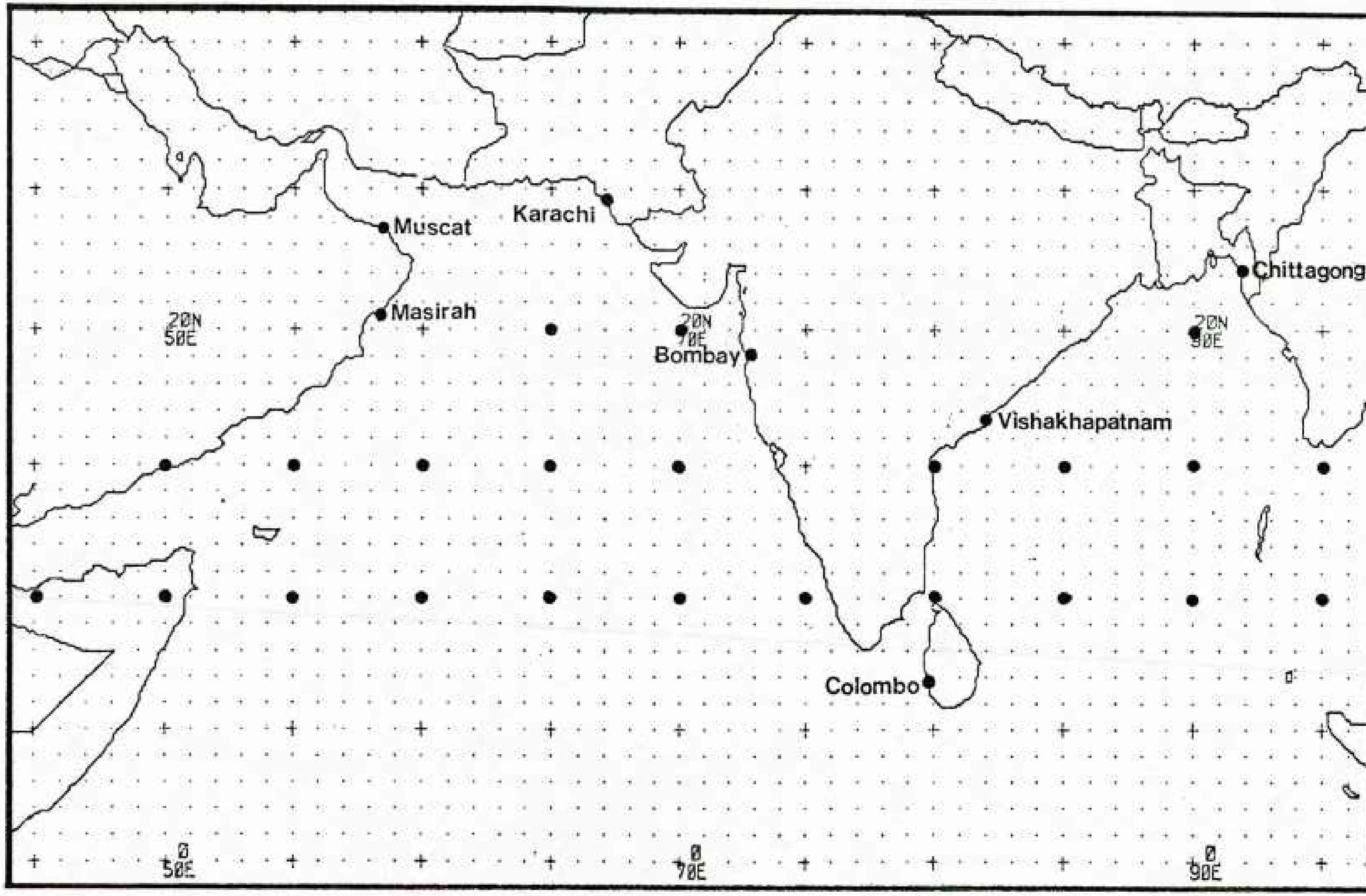

Figure 2. Selected test points (30) in the North Indian Ocean. Included are seven named cities of interest to the U.S. Navy.

Table 1. Instantaneous Probabilities.
50 kt winds - Expected versus Observed.

	50 KT								
	24 Hr			48 Hr			72 Hr		
A<u><</u>P<B	N	E	O	N	E	O	N	E	O
< ½%	643	1	1	312	0	0	88	0	0
½ - 1½	41	0	0	18	0	0	2	0	0
1½ - 3½	6	0	0	0	0	0	0	0	0
3½ - 7½	0	0	0	0	0	0	0	0	0
7½ - 15½	0	0	0	0	0	0	0	0	0
15½ - 31½	0	0	0	0	0	0	0	0	0
31½ - 63½	0	0	0	0	0	0	0	0	0
> 63½	0	0	0	0	0	0	0	0	0
ALL	690	1	1	330	0	0	90	0	0

Table 2. Instantaneous Probabilities.
30 kt winds - Expected versus Observed.

	30 KT								
	24 Hr			48 Hr			72 Hr		
A<u><</u>P<B	N	E	O	N	E	O	N	E	O
< ½%	564	0	0	260	0	0	74	0	0
½ - 1½	49	1	1	35	0	0	11	0	0
1½ - 3½	51	1	1	35	1	1	5	0	0
3½ - 7½	26	1	1	0	0	0	0	0	0
7½ - 15½	0	0	0	0	0	0	0	0	0
15½ - 31½	0	0	0	0	0	0	0	0	0
31½ - 63½	0	0	0	0	0	0	0	0	0
> 63½	0	0	0	0	0	0	0	0	0
ALL	690	3	3	330	1	1	90	0	0

Table 3. Time Integrated Probabilities.
50 kt winds - Expected versus Observed.

	50 KT								
	24 Hr			48 Hr			72 Hr		
A≤P<B	N	E	O	N	E	O	N	E	O
< ½%	610	0	0	262	0	0	67	0	0
½ - 1½	43	0	0	43	0	0	12	0	0
1½ - 3½	32	1	1	22	1	0	11	0	0
3½ - 7½	5	0	0	3	0	1	0	0	0
7½ - 15½	0	0	0	0	0	0	0	0	0
15½ - 31½	0	0	0	0	0	0	0	0	0
31½ - 63½	0	0	0	0	0	0	0	0	0
> 63½	0	0	0	0	0	0	0	0	0
ALL	690	1	1	330	1	1	90	0	0

Table 4. Time Integrated Probabilities.
30 kt winds - Expected versus Observed.

	30 KT								
	24 Hr			48 Hr			72 Hr		
A≤P<B	N	E	O	N	E	O	N	E	O
< ½%	493	0	0	212	0	0	55	0	0
½ - 1½	80	0	1	39	0	0	8	1	0
1½ - 3½	67	1	2	56	1	1	20	0	0
3½ - 7½	37	2	2	16	1	1	7	0	1
7½ - 15½	13	1	1	7	1	1	0	0	0
15½ - 31½	0	0	0	0	0	0	0	0	0
31½ - 63½	0	0	0	0	0	0	0	0	0
> 63½	0	0	0	0	0	0	0	0	0
ALL	690	4	6	330	3	3	90	1	1

4.0 Operational Products

The North Indian Ocean wind probability program will be available for seven preselected points.* Probabilities will be given in two modes, instantaneous and time integrated, and at 0, 12, 24, 36, 48, 60 and 72 hours after the warning time. The instantaneous probability will be the probability <u>at</u> the stated time (i.e., 12 hr) and the time integrated probability will be summed for the 0 to <u>X</u> hour time interval for an estimate of the probability that the event will be observed within that period of time.

The greatest source of probable error for the WINDPIO program will be erroneous input data. An internal check for unusual motion (expected to occur only 5% of the time in nature) will be made and suspect motion flagged. The user should then recheck input data for accuracy.

When the forecast track approaches a land mass, the forecaster should be aware of program bias. This should be minor for seaward approach to low coastal areas or over smaller islands. However, in other cases land influences will appear as rapid decreases in the instantaneous wind probabilities (especially 50 kt winds) near forecast landfall time. This will bias probabilities - overstate them for inland sites and understate them for coastal sites.

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*Locations: Muscat, Masirah Island, Karachi and Bombay in the Arabian Sea, and Colombo, Vishakhapatnam and Chittagong in the Bay of Bengal (also shown in Figure 1).

Time integrated probabilities will be less biased. This problem is caused by wind forecasts being influenced by track forecasts where landfall is concerned. A bad track forecast may cause a bad wind forecast. This was not accounted for either in development nor testing; hence the test results simulate expected actual operational results and some of the minor disparities between expected and observed occurrences no doubt stem from this.

Figure 3 depicts a standard output of WINDPIO for Cyclone 31-81, 9 December 1981. Probabilities are provided at 12 hour intervals for strike, 50 and 30 kt winds in both instantaneous and time integrated modes. The format HHPIPS where HH is hours after forecast effective time, PI and PS are the instantaneous and time integrated probability rounded to the nearest whole percent. The letters "IN" mean insignificant or less than one half percent while "THREAT NIL" means all probabilities were less than one percent.

```
STRIKE AND WIND PROBABILITY FORECAST
CY 31-81 090800Z

MUSCAT        THREAT NIL

MASIRAH IS    THREAT NIL

KARACHI       THREAT NIL

BOMBAY        00ININ 121NIN 24ININ 36ININ 48ININ 60ININ 72ININ
   50 KNOT    00ININ 12ININ 24ININ 36ININ 48ININ 60ININ 72ININ
   30 KNOT    00ININ 12ININ 24ININ 36ININ 48IN01 60IN02 72IN03

COLOMBO       00ININ 12ININ 24ININ 36ININ 48ININ 60ININ 72ININ
   50 KNOT    00ININ 12ININ 24ININ 36ININ 48ININ 60ININ 72ININ
   30 KNOT    00ININ 12ININ 24ININ 36ININ 48IN01 60IN02 72IN03

VISKAHPTNM    00ININ 120102 240307 360210 480111 600112 720112
   50 KNOT    000202 120712 240716 360518 480319 600219 720220
   30 KNOT    002626 123236 242937 362037 481437 601037 720838

CHITTAGONG    00ININ 121NIN 24IN01 360204 480308 600211 720213
   50 KNOT    00ININ 12ININ 240103 360409 480513 600516 720517
   30 KNOT    00ININ 120204 241014 361921 482225 602127 721928

FOR METEOROLOGISTS;  FORECAST CONFIDENCE TABLE
     TIME PROB  DIST PROB DIST PROB
     12HR  15    50   15    75   70
     24HR  24   100   22   150   54
     48HR  33   200   26   300   41
     72HR  38   300   27   450   35

PROBABILITIES BASED ON FOLLOWING FORECAST
001640866075 121720869070 241800872065 481980892045 722080922030
```

Figure 3. Sample WINDPIO output for cyclone 30-81, 9 December 1981. See text for format. This product is based on an official forecast issued by the Joint Typhoon Warning Center, Guam.

5.0 Summary

The wind probability model for the North Indian Ocean is largely based on the wind probability program for the Atlantic. Many features of wind probability programs for the eastern and western North Pacific have also been incorporated. All of these programs are operational or soon to be operational. Test results of the North Indian Ocean wind probability program (WINDPIO) demonstrated excellent agreement between expected and observed results. Operatioal products are available both in message form as described herein and in the Navy Environmental Display System (NEDS) as plotted charts.

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MET. OFFICER
FPO SAN FRANCISCO 96677

CINCLANT
NAVAL BASE
NORFOLK, VA 23511

CINCPAC
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STAFF CINCPAC J37
CAMP SMITH, HI 96861

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(OP-952)
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WASHINGTON, DC 20390

CHIEF OF NAVAL OPERATIONS
NAVY DEPT. OP-986G
WASHINGTON, DC 20350

CHIEF OF NAVAL OPERATIONS
U.S. NAVAL OBSERVATORY
DR. R. W. JAMES, OP-952D1
34TH & MASS. AVE., NW
WASHINGTON, DC 20390

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OJCS (J-33)
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WASHINGTON, DC 20301

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MONTEREY, CA 93940

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459 SUMMER ST.
BOSTON, MA 02210

COMMANDING OFFICER
NORDA, CODE 335
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NAVAL AIR STATION
NORFOLK, VA 23511

COMMANDING OFFICER
NAVPOLAROCEANCEN
NAVY DEPT.
4301 SUITLAND RD.
WASHINGTON, DC 20390

COMMANDING OFFICER
U.S. NAVOCEANCOMCEN
BOX 12, COMNAVMARIANAS
FPO SAN FRANCISCO 96630

COMMANDING OFFICER
U.S. NAVOCEANCOMCEN
BOX 31 (ROTA)
FPO NEW YORK 09540

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OCEANOGRAPHY DEPT.
U.S. NAVAL ACADEMY
ANNAPOLIS, MD 21402

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NAVAL WAR COLLEGE
GEOPHYSICS OFFICER
NEWPORT, RI 02840

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LIBRARY, AIR-00D4
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NAVAIRSYSCOM, AIR-333
WASHINGTON, DC 20361

COMMANDER
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MET. SYS. DIV.
WASHINGTON, DC 20360

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LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93940

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AWS/DN
SCOTT AFB, IL 62225

USAFETAC/TS
SCOTT AFB, IL 62225

3350TH TECH. TRNG GRP.
TTGU/2/STOP 623
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AFGL/LY
HANSCOM AFB, MA 01731

5WW/DN
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SERVICE SCHOOL COMMAND
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CHANUTE AFB, IL 61868

HQ. 1ST WEA. WING/DN
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DEFENSE TECH. INFORMATION
CENTER, CAMERON STATION
ALEXANDRIA, VA 22314

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ENV. & LIFE SCIENCES
UNDERSEC OF DEFENSE FOR
RSCH & ENG, E&LS
RM. 3D129, THE PENTAGON
WASHINGTON, DC 20505

FEDERAL COORDINATOR FOR
METEORO. SERV. & SUPP.
RSCH (OFCM)
11426 ROCKVILLE PIKE
SUITE 300
ROCKVILLE, MD 20852

DIRECTOR
NATIONAL HURRICANE CENTER
NOAA, GABLES ONE TOWER
1320 S. DIXIE HWY
CORAL GABLES, FL 33146

DIRECTOR, INTL AFFAIRS
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6010 EXECUTIVE BLVD.
ROCKVILLE, MD 20852

DIRECTOR (AOML)
NATIONAL HURRI. RSCH. LAB.
1320 S. DIXIE HWY.
CORAL GABLES, FL 33146

HEAD, ATMOS. SCI. DIV.
NATIONAL SCI. FOUNDATION
1800 G. ST., NW
WASHINGTON, DC 20550

THE EXECUTIVE DIRECTOR
AMERICAN METEORO. SOC.
45 BEACON ST.
BOSTON, MA 02108

AMERICAN METEORO. SOC.
MET. & GEOASTRO. ABSTRACTS
P.O. BOX 1736
WASHINGTON, DC 20013

DIRECTOR, JTWC
BOX 17
FPO SAN FRANCISCO 96630

MR. W. G. SCHRAMM/WWW
WORLD METEOROLOGICAL
ORGANIZATION
CASE POSTALE #5, CH-1211
GENEVA, SWITZERLAND

DIRECTOR, INDIAN INST. OF
TROPICAL METEOROLOGY
RAMDURG HOUSE
PUNE 411-005, INDIA

NATIONAL INSTITUTE OF
OCEANO., REGIONAL CEN.
P.B. 1913
COCHIN-682018
INDIA

SCIENTIFIC ADVISERS TO
CHIEF OF NAVAL STAFF
NAVAL HEADQUARTERS
NEW DELHI-22, INDIA

METEOROLOGICAL DEPT.
GOVERNMENT OF INDIA
NEW DELHI-3, INDIA

DIRECTOR GENERAL
METEOROLOGICAL DEPT.
GOVERNMENT OF INDIA
NEW DELHI, 3 INDIA

METEOROLOGY DEPT.
ANDHRA UNIVERSITY
WALTAIR, INDIA A530-003